Promise and challenges of the future LHCb upgrade

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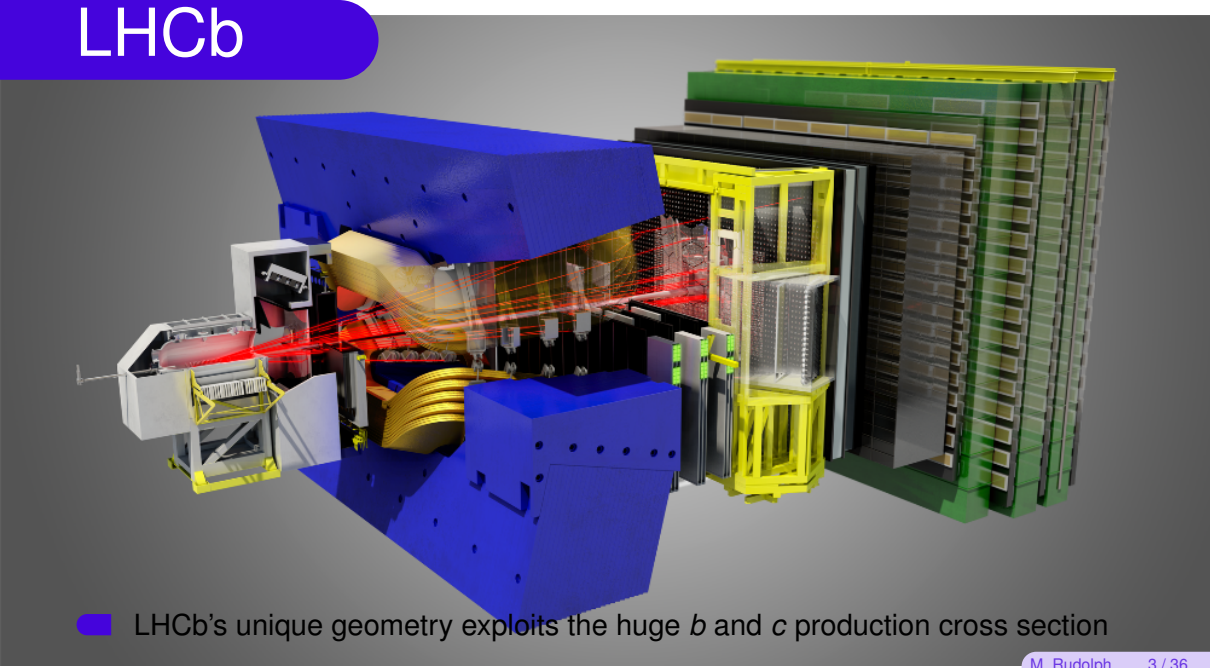
Introduction

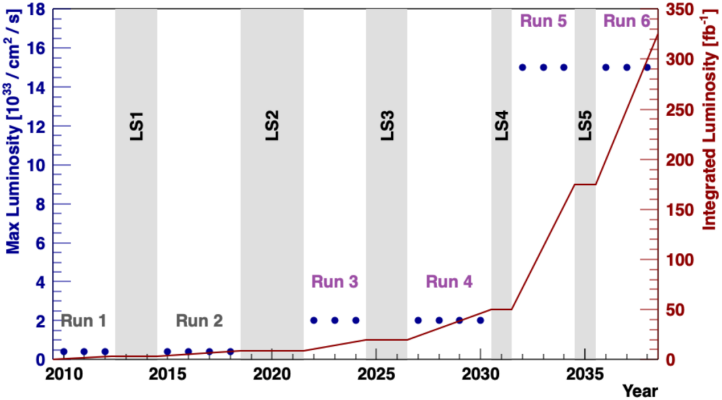
- LHC Runs 1 and 2 have outstanding physics results
- One of the strongest hint of new physics beyond SM from *b* decays: lepton flavor universality violation
- Rare processes: running LHCb beyond Run 4 will not systematically limit many measurements
- High luminosity conditions bring additional detector challenges for a future Upgrade II

LHCb



- LHCb's unique geometry exploits the huge *b* and *c* production cross section

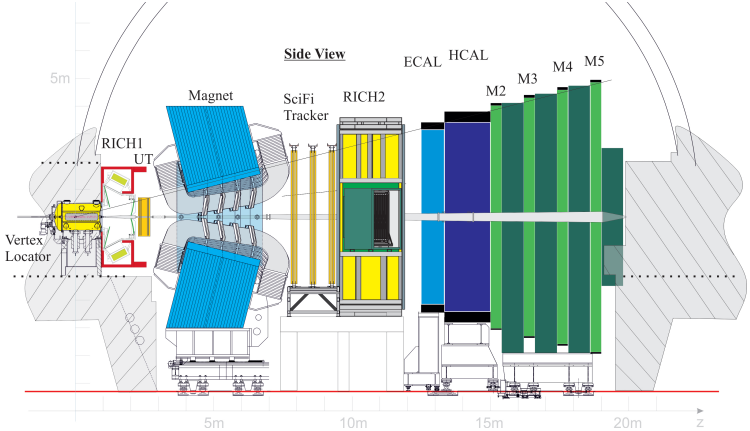
LHCb in LHC runs



- Run 1+2: 9 fb^{-1}
- Run 3+4: 50 fb^{-1}
- Run 5+6: 300 fb^{-1}?

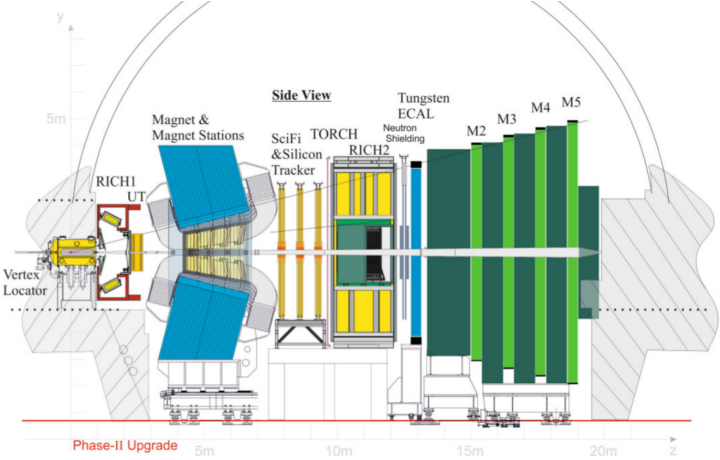
Upgrade I

- Now installing for Runs 3 and 4
- Biggest change: flexible all software trigger



Upgrade II

- Proposed for long shutdown before Run 5
- Must operate at increased pile-up with similar or improved sensitivity



Status

European Strategy Update

"The full physics potential of the LHC and the HL-LHC, including the study of flavour physics and the quark-gluon plasma, should be exploited."

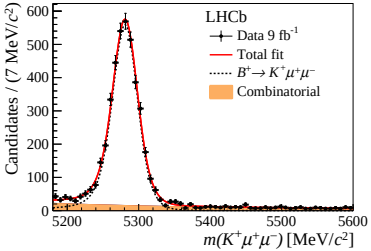
- Framework TDR soon to go for full approval with LHCC

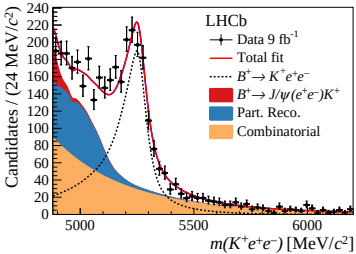
Physics: now and future

R_K

$$R(K) = \frac{\mathscr{B}(B^+ \to K^+\mu^+\mu^-)}{\mathscr{B}(B^+ \to K^+e^+e^-)}$$
$$= 0.846^{+0.044}_{-0.041}$$
$$1.1 < q^2 < 6\,\text{GeV}^2$$

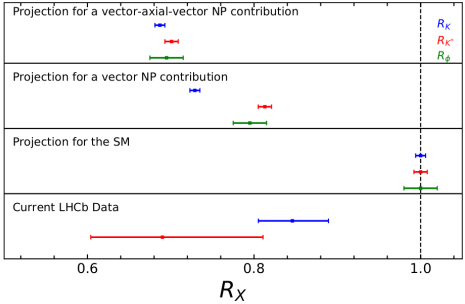
- One of many measurements suggesting muon rate is low!
- Legacy Run 2 measurements still being finalized





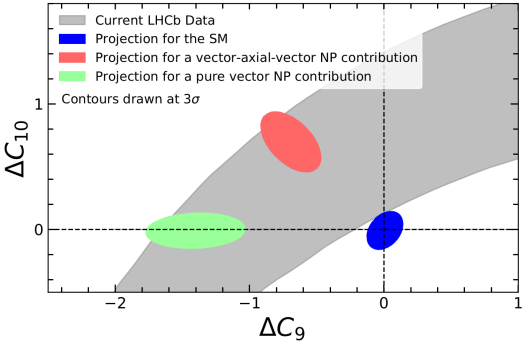
The future

- Ratios are theoretically clean
- Sensitivity improves through Upgrade II
- Beyond one number: precision to test different new physics models



Angular analysis

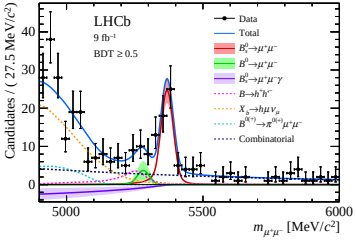
- For muon mode: key part of current anomalies
- Upgrade II allows direct experimental comparison of muon and electron modes
- Constraints directly on effective field theory coefficients

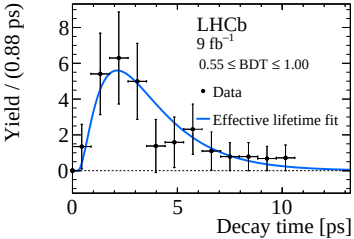


$B_s^0 \to \mu^+\mu^-$

$$\mathscr{B}\left(B_s^0 \to \mu^+\mu^-\right) = \left(3.09^{+0.46+0.15}_{-0.43-0.11}\right) \times 10^{-9}$$

- Single most precise measurement, includes effective lifetime
- With Upgrade II can measure to 10% the relative rate for $B^0 \to \mu^+\mu^-$





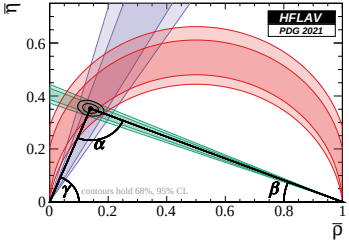
CKM angle γ

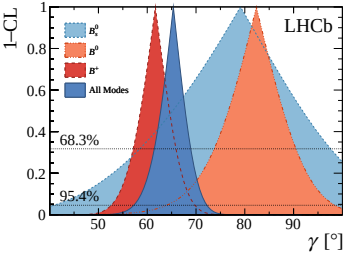
- 15 B decays and 9 D^0 decays to simultaneously measure γ and charm mixing parameters x, y
- Using tree level decays with negligible theoretical uncertainty

$$\gamma = \left(65.4^{+3.8}_{-4.2}\right)^{\circ}$$

$$x = \left(0.400^{+0.052}_{-0.053}\right)\%$$

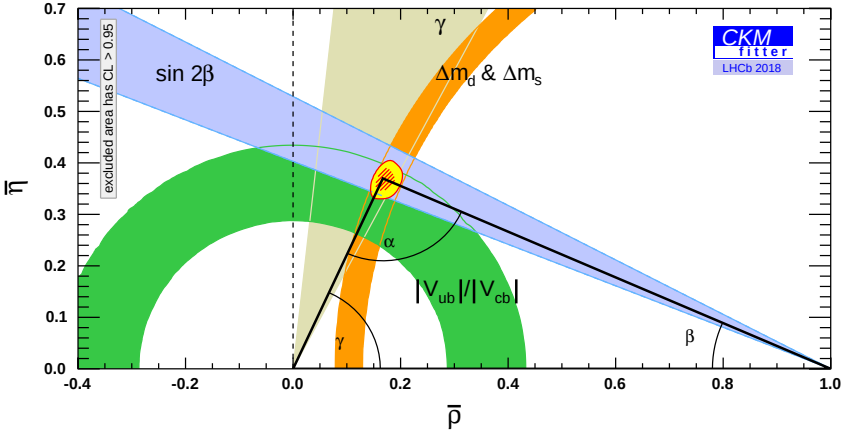
$$y = \left(0.630^{+0.033}_{-0.030}\right)\%$$





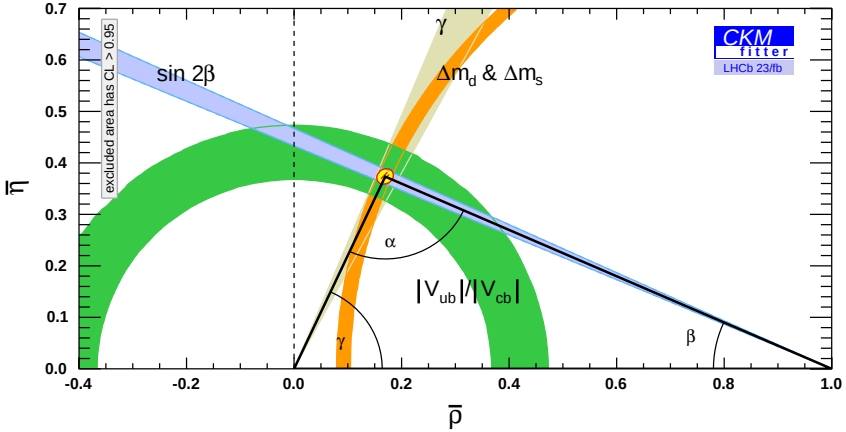
Unitarity triangle

Now



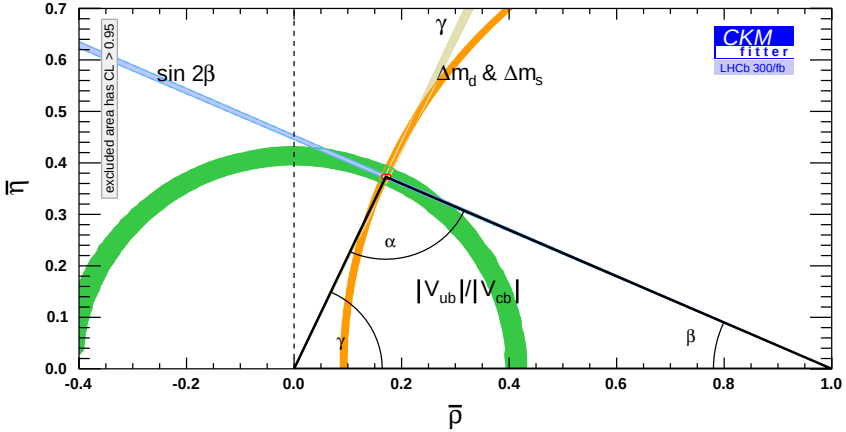
Unitarity triangle

Run 3



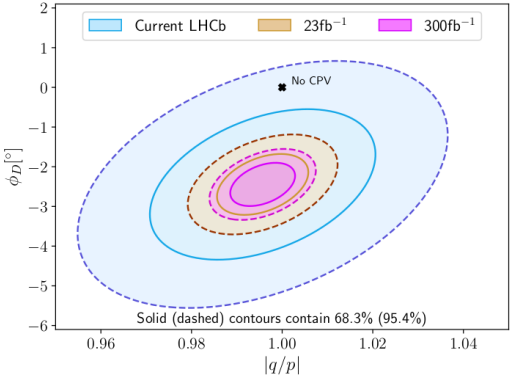
Unitarity triangle

Upgrade II



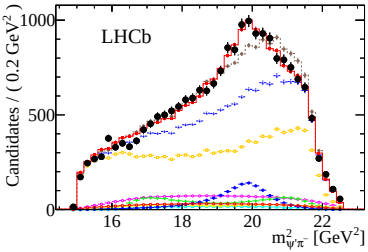
Charm mixing and CPV

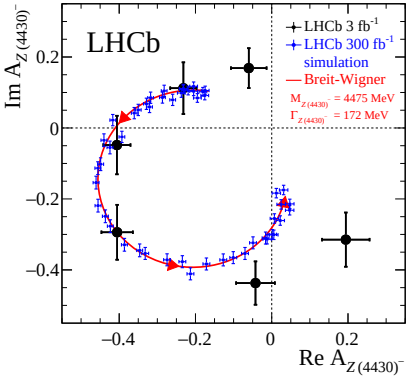
- 5σ observation of D^0 mass difference
- Observation of CPV in charm
- Upgrade II only place to precisely measure CPV parameters



Exotic spectroscopy

- One example of amplitude of tetraquark $Z(4430)^-$ in $B^0 \to \psi' \pi^- K^+$



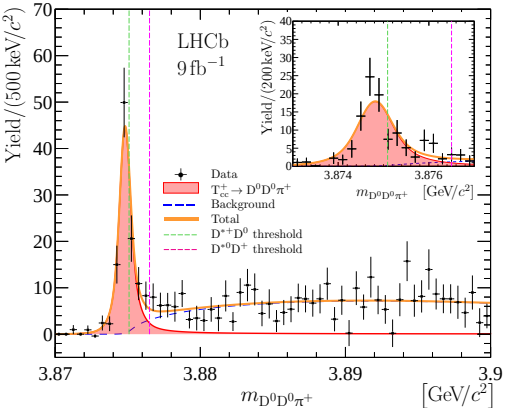


- Many possibilities in B, B_s^0, and Λ_b^0 decays

New T_{cc}

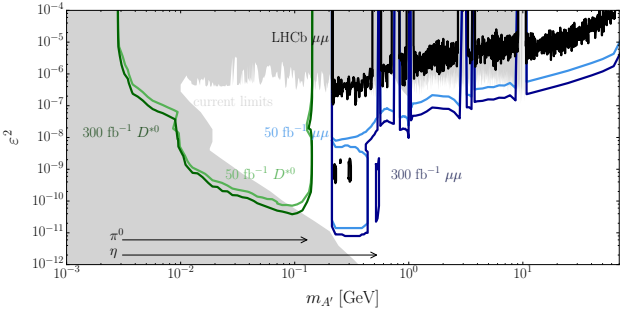
- Just below $D^{*+}D^0$ mass
- A strong/EM stable T_{bb} may exist

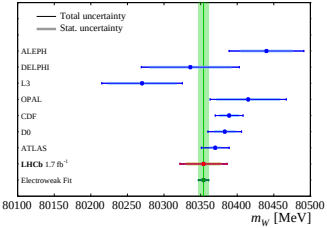
$$\delta m_{\mathrm{BW}} = -273 \pm 61 \pm 5^{+11}_{-14}\,\mathrm{keV}$$
$$\Gamma_{\mathrm{BW}} = 410 \pm 165 \pm 43^{+18}_{-38}\,\mathrm{keV}$$

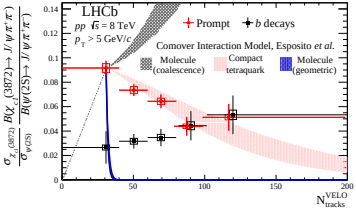


And more!

- Only a taste of the physics program!
- Also sensitivity for
  - Long lived particles
  - Electroweak physics
  - Nuclear physics







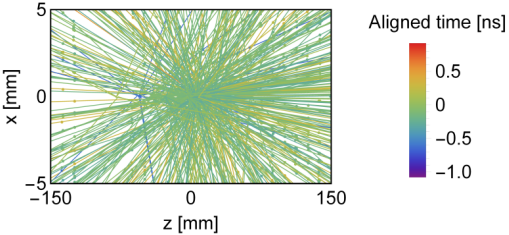
Challenge of Upgrade II

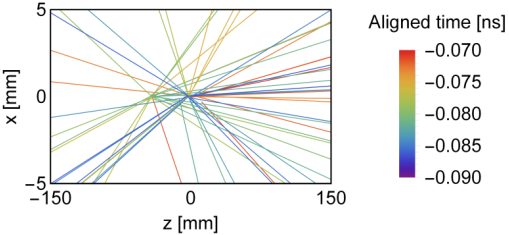
Challenge of Upgrade II

- Need to maintain performance at $\mathscr{L} = 1.5 \times 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}$ to get to $300\,\mathrm{fb}^{-1}$ in Runs 5+6
- ≈ 40 collisions per bunch crossing
- Occupancy, radiation, and readout are particular challenges
- Currently in early planning: options available, dedicated R&D needed

Occupancy

Velo

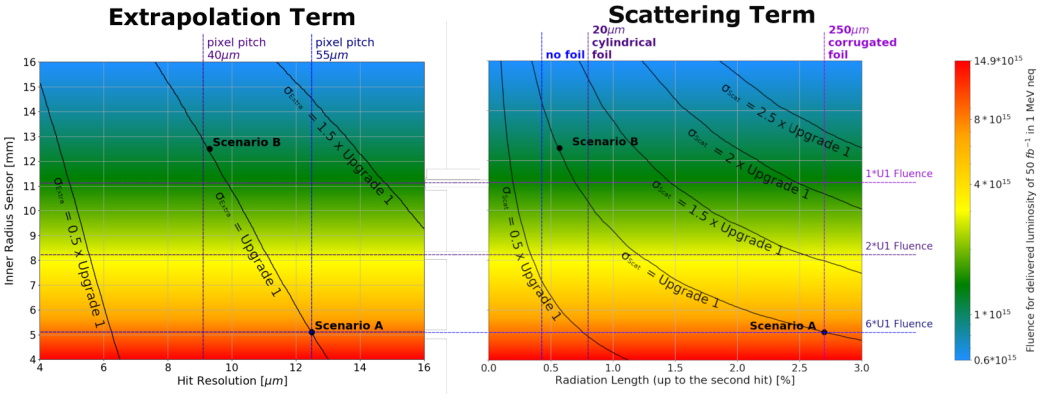




- Timing effectively reduces vertex overlaps

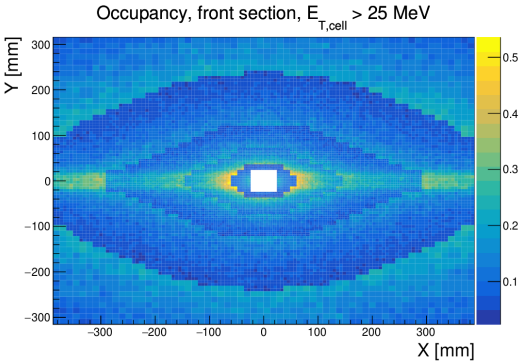
Radiation

Velo



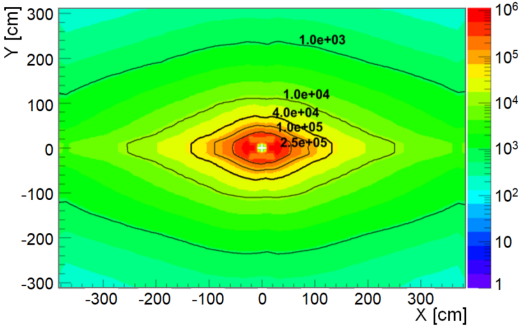
Occupancy

ECAL



Radiation

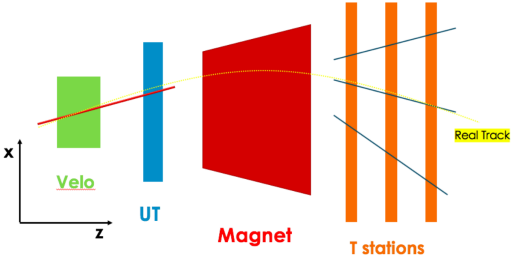
ECAL



Occupancy

Ghosts

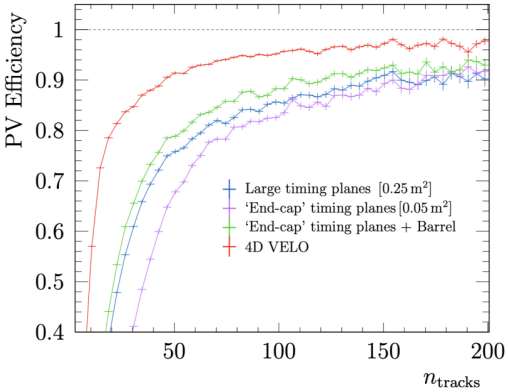
- Combinatorics over long distances result in mismatches
- Many strategies to mitigate
  - Improved segmentation
  - Use of timing
  - Better software algorithms



Picosecond timing

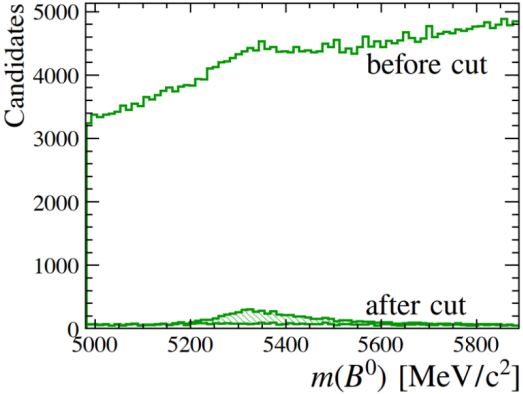
4D tracking

- Timing crucial for VELO: need 20 ps/track
- full 4D much better than timing layers
- Challenging in high radiation environment
- 3D pixel sensors potential choice

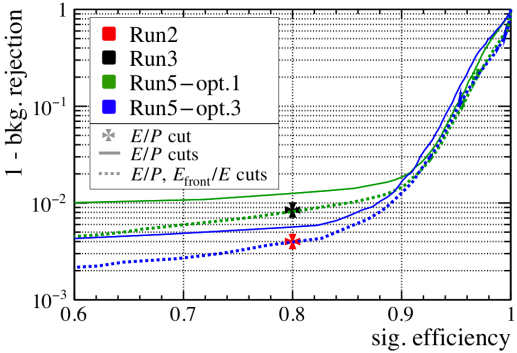


ECAL

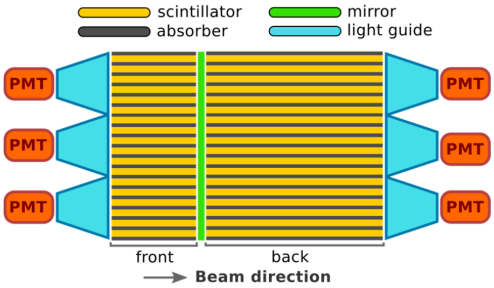
- Timing rescues signal: *e.g.* $B^0 \to \pi^+\pi^-\pi^0$



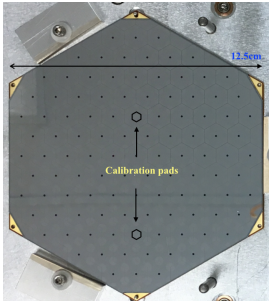
- Improving *e* would be a big gain *e.g.* $K^{*0}e^+e^-$



ECAL options

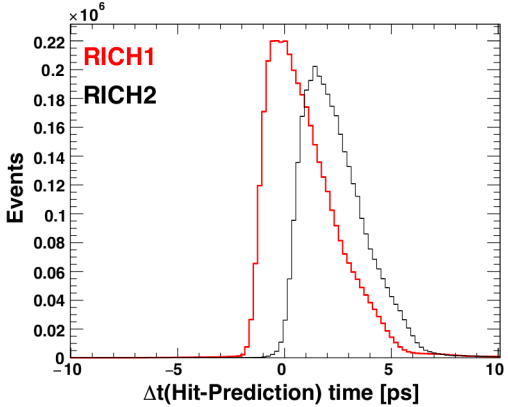


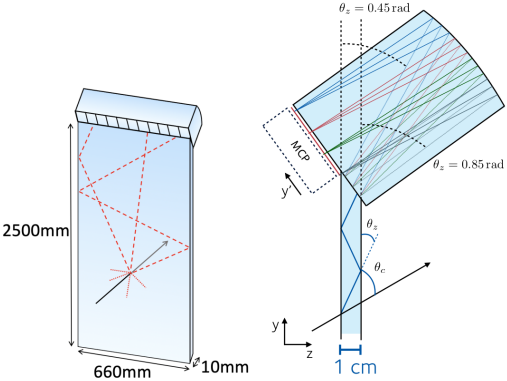
- Crystal (GAGG) with possible timing layer of LAPPD or Si midshower



- Silicon tungsten a la CMS HGCAL

RICH and TORCH

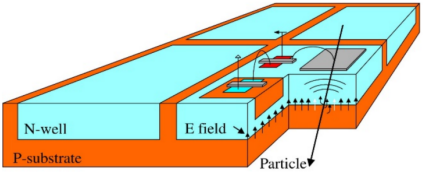


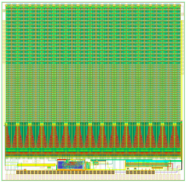


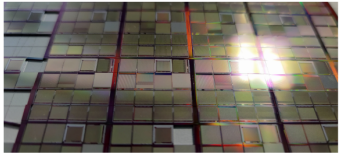
- RICH may use timing from SiPMs, LAPPDs or other MCPs for matching photons with tracks
- New TORCH for TOF PID at low momentum

Tracking stations

- Monolithic pixel sensors being investigated for tracking stations
- Much increased granularity over current tracking

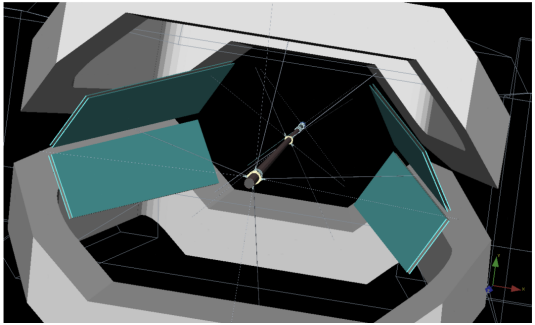






Magnet stations

- Chance to improve: tracking inside magnet picks up low momentum tracks
- May be installed for Run 4



DAQ

- LHCb will produce up to 200 Tb/s
- Extreme challenge both for readout chain, and for first stages of software trigger algorithms
- Detailed studies needed for potential options in *e.g.* local reconstruction with FPGAs

Conclusion

- LHCb has produced world-best measurements and intriguing hints for new physics
- A second upgrade is needed to fully exploit the large luminosity available from the HL-LHC
- There are many detector R&D challenges remaining to solve for Upgrade II, including the full use of picosecond timing